

# **Warm Oceans Raise Land Temperatures in 2004**

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Earth's sea surface temperatures (SSTs) were the 3<sup>rd</sup> warmest in the past 125 years during 2004. Land surface temperatures were the 4<sup>th</sup> warmest, and globally averaged temperatures likewise ranked 4<sup>th</sup> highest since 1880 (Levinson, 2005).

In this article, the influence of warm oceans on land surface temperatures is diagnosed. Our purpose is to draw attention to the influence that current sea temperature states are having upon terrestrial temperatures. The analysis seeks to clarify the causes for recent land warmth, and ultimately raises questions on origins for the oceanic warmth itself.

All oceans witnessed warm sea surface conditions in 2004 (relative to a 1961-1990 base period), with only the middle latitudes of the Southern Ocean experiencing below average values (Figure 1). Much of this warmth was concentrated north of 30°S, and included a weak El Niño event in the tropical central Pacific. A more detailed discussion of the 2004 El Niño is provided by M. McPhaden in the "State of the Climate in 2004" report (Levinson 2005). The all-ocean averaged SST departure for 2004 was consistent with an increasing trend during recent decades, and has been accompanied by rising world ocean heat content during the same period (Levitus et al. 2005).

Terrestrial warmth in 2004 (relative to a 1961-1990 base period) was witnessed at all locations between 45°N-45°S. The greatest departures occurred over interior Eurasia and western North America which experienced up to +2°C annual departures. Cold departures were confined to northeastern Asia, northern Canada, and eastern Antarctica (Fig. 2, top).

Consistent with the considerable warmth of land and ocean surfaces, much of the global troposphere was also warm in 2004. The thermal expansion of the tropospheric column, whose top is roughly approximated by the 200 mb pressure surface, is demonstrated by the increase in elevation of that surface world-wide (Fig. 2, bottom). Particularly pronounced were the raised heights over the Arctic, the tropics, and much of the Southern Ocean.

Diagnosing the ocean's contribution to this terrestrial and global tropospheric warmth is best amenable to the use of climate simulations subjected to the observed sea surface conditions. A suite of Atmospheric General Circulation Model (AGCM) experiments has been conducted as part of a coordinated multi-agency climate diagnostics consortium (Barnston et al. 2005). This activity undertakes the enterprise of establishing attribution of observed climate states in near real-time. It is an effort beyond the resources of any single entity since a key requirement is to generate a statistical measure of the probability distribution of our target variable (i.e., 2004 land surface temperatures) drawn from a very large population of realizations.

Five different AGCMs are used in the analysis. These have been subjected to the monthly, global variations of observed SSTs during 2004, and the experiments are part of long simulations that span the latter-half of the 20<sup>th</sup> Century. An ensemble of experiments has been performed for each model in which identical SST evolutions have been specified, but the individual members differed only in their atmospheric initial conditions (start dates were 1950). A total of 81 simulations have been generated from these five models, whose basic characteristics are further detailed in Table 1 of Barnston et al. (2005).

Key diagnostics from the experiments are the ensemble anomalies --- calculated by averaging the 81 members, and the inter-experiment deviations ---calculated from the spread of anomalies among the 81 members. The ensemble average diagnoses the SST-forced climate signal. There is uncertainty in signal detection owing to different model sensitivities due to the diversity of physical representations employed in the various AGCMs. There is also uncertainty in attributing the single realization of the observed 2004 land surface anomalies to the SST-forced signal alone due to random internal atmospheric variability. Both of these uncertainty sources are sampled in our analysis, and are depicted by analyzing the overall spread among the 81 runs and among the 5 model ensemble means.

Evidence that SSTs contributed importantly to wide-spread terrestrial warmth in 2004 is provided by the ensemble averaged AGCM land temperature signal (Fig. 3, top). A warm response is pervasive over Eurasia, Africa, Australia, South America, and most of North America. The North American warm signal is most prominent in the western and northern reaches of the continent. This overall warm response is remarkably similar to the observed 2004 terrestrial warmth.

The zonally averaged land temperature signal (Fig. 3 , right plots) is positive at all latitudes as was observed, though the strength of that signal is up to a factor of 2 weaker than the observed anomaly over the Northern Hemisphere extratropics. In addition to the blue curves that depict the 5-model averaged zonal profiles, the extreme lowest and highest values of the zonal mean anomalies among the 5 AGCMs are indicated by the green and red curves, respectively. The robustness of the warm signal is confirmed by the fact that each model yields the same signed-response of zonal mean land surface temperatures.

Sea surface conditions of 2004 were also of great consequence for global tropospheric warming. The AGCMs predict thermal expansion of the troposphere at virtually all locations, as measured by an increasing elevation of the 200 mb surface (Fig. 3, bottom), consistent with the pervasive atmospheric warmth observed. The zonally averaged profile of this warm signal exhibits a distinctive tropical maximum, one that is qualitatively similar to that seen during El Niño years (Kumar and Hoerling, 2003) .

The global tropospheric warmth appears to result from more than just a teleconnection response to El Niño. For example, the amplitude of the 200 mb height increases in the tropics is considerably greater than expected from weak El Niño forcing. Furthermore,

the simulated above normal heights in the middle latitudes is opposite in sign to the canonical negative height response to El Niño (Kumar and Hoerling 2003)

The model results suggest a tropospheric warm response to additional, non-El Niño related warm tropical SST anomalies. We especially note the positive SST departures over the Indian Ocean and western Pacific that coincide with the region experiencing a multi-decadal warming trend (Knutson et al. 1999). The tropospheric response to such “warm pool” warmth has been previously shown to include both tropical and midlatitude above normal heights (Hoerling et al. 2004). On the other hand, the impact of pervasive warmth over the Northern Hemisphere extratropical oceans is unclear, and additional model experiments would be required to quantify their contribution to the terrestrial warmth, especially over Eurasia and North America.

Globally averaged land surface temperature departures for 2004 were computed for each of the 81 separate realizations, the results of which are summarized by the probability distribution function (PDF) in Fig. 4. Shown also by the long red tic-mark is the observed land temperature departure. Every member simulates terrestrial warmth for 2004, indicating that the *sign* of the temperature anomaly was fully determined by the state of world-wide SSTs. The mean value of simulated warmth is  $+0.6^{\circ}\text{C}$ , close to the observed warm departure of  $+0.8^{\circ}\text{C}$ .

There is considerable range in the amplitude of simulated warmth for 2004. This arises almost equally from the different land temperature sensitivities of the five AGCMs and from purely internal atmospheric variability. Although not shown, the latter is found to be quite similar for each of the models, with the standard deviation of land temperature resulting from such purely internal “atmospheric noise” being  $0.1^{\circ}\text{C}$ . By comparison, the standard deviation of land temperatures *signals* among the 5 models is also  $0.1^{\circ}\text{C}$ , with the least sensitive model yielding a  $+0.4^{\circ}\text{C}$  compared to a  $+0.7^{\circ}\text{C}$  response in the most sensitive model. The combined standard deviation among all 81 members analyzed in Fig. 4 is  $0.14^{\circ}\text{C}$ , a value nearly identical to the linear combination of signal and atmospheric noise uncertainty sources.

One conclusion drawn from this attribution exercise is that the observed terrestrial warmth of 2004 was entirely consistent with a global response to sea surface temperatures over the world oceans. The fact that the oceans were the 3<sup>rd</sup> warmest within the modern instrumental record was of great consequence to continental climates. Our multiple re-enactments of the 2004 climate indicated that terrestrial temperatures could have differed in amplitude from those observed by chance alone. Therefore, it may have been purely coincidence that the observed  $+0.8^{\circ}\text{C}$  land temperature departure of 2004 resided in the low probability state of our model simulations ----the vast majority of runs produced weaker terrestrial warmth than observed with only 2 out of 81 exceeding the observed warmth. Yet, we also recognize that all of the AGCM simulations employed specified atmospheric chemical compositions of trace gases. For example, carbon dioxide was assigned to 20<sup>th</sup> Century climatological values in these runs, with those ranging from 330 to 355 ppm in the 5 AGCMs. These correspond roughly to 1980 conditions, and differ from the 380 ppm in 2004 (Levinson 2005). Thus, the

experiments have not completely represented all the “external forcings” that could have influenced terrestrial temperatures in 2004. It is reasonable to speculate that the direct radiative effect of increased trace gases in 2004 may also have contributed to terrestrial warmth in 2004. Future attribution efforts that incorporate trace gas forcings (including also aerosols) will clarify their efficacy relative to the ocean influence that was diagnosed herein.

A further conclusion drawn from our simulation results is that global terrestrial warmth was unavoidable during 2004 owing to the SST conditions. A central question then becomes the attribution for the SSTs themselves. Though beyond the scope of this article, some discussion is in order. Can, for example, pervasive ocean warmth in 2004 be attributed to greenhouse gas (GHG) forcing? Previous efforts to explain trends in global SSTs in the latter half of the 20<sup>th</sup> Century indicate that warming of the tropical Indo-Pacific warm pool (one of the conditions in 2004) is consistent with such forcing (Knutson et al. 1999). The SST warmth in all basins is consistent with elevated ocean heat content (Levitus et al. 2005), the trend component of which has been attributed to increasing GHG forcing in coupled ocean-atmosphere model experiments (Barnett et al. 2001, Levitus et al. 2000). These ocean heat content trends are themselves consistent with new evidence from satellite measurements that the Earth is now absorbing more energy from the Sun than it is emitting to space (Hansen et al. 2005).

There are also indications that some of the SST warmth in 2004 was from natural causes, in particular the El Niño being a phenomenon of unforced variability internal to the coupled ocean-atmosphere system. North Atlantic warmth has been prevalent since the late 1990s, and may also reflect the signal of natural multi-decadal SST variability in that basin (e.g., Delworth and Mann 2000). The relative contribution of natural variability and anthropogenic forcing to the warmth of 2004 SSTs will require analysis of ensemble multi-model coupled integrations with GHG forcings.

Providing near-real assessments of the origin of climate states, and the role of specific forcings is of great importance not only for understanding the role of natural and anthropogenic influences on climate, but is also expected to advance efforts on multi-annual climate prediction. While having only explored the role of ocean surface conditions for terrestrial climate herein, the fact that such a large influence was isolated serves to further confirm the leading role of oceans in climate variability and change. To the extent that *natural origins* for the SST states of 2004 were important, the simulations indicate that appreciable global mean land temperature variations can occur that may temporarily either enhance or mask anthropogenic signals of land temperature change. To the extent that *GHG origins* for the SST states of 2004 were important, the simulations indicate that much of the global mean land warmth is (at least currently) arising from a feedback processes involving air-sea interactions. In either situation, anticipating the future trajectory of the oceans is argued to be of great significance for multi-annual climate projections as a whole.

*Acknowledgments*

The support offered by NOAA's Office of Global Program's Climate Dynamics and Experimental Prediction Program and CLIVAR are gratefully acknowledged. Dr. M. Hoerling also acknowledges support provided by the Geophysical Fluid Dynamics Laboratory of Princeton.

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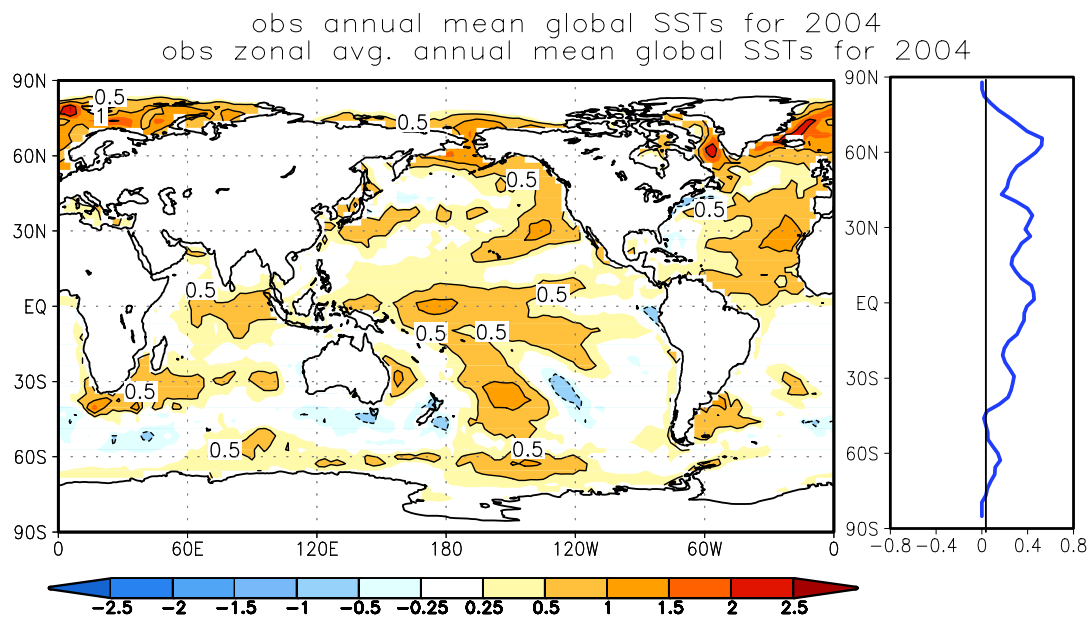


Fig. 1. The observed 2004 annually averaged sea surface temperatures anomalies ( $^{\circ}\text{C}$ ). Right side curve is the zonally averaged sea surface temperature anomalies. Reference period is 1961-1990.

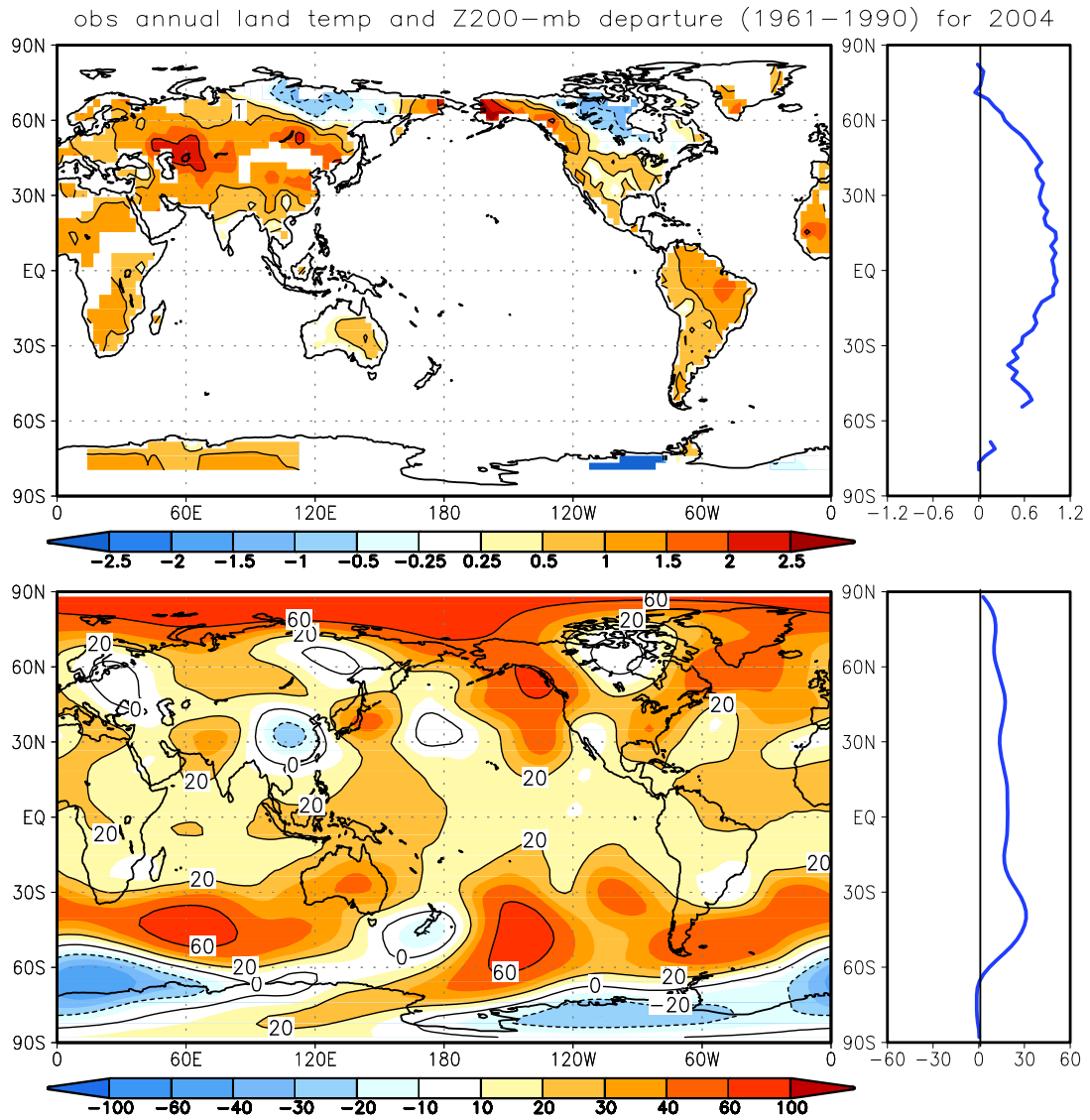


Fig. 2. The observed 2004 annually averaged land surface temperature anomalies ( $^{\circ}\text{C}$ , top) and 200 mb geopotential height anomalies (m, bottom). Right side curves in top and bottom are the zonally averaged land surface temperature and 200 mb height anomalies, respectively. Reference period is 1961–1990.

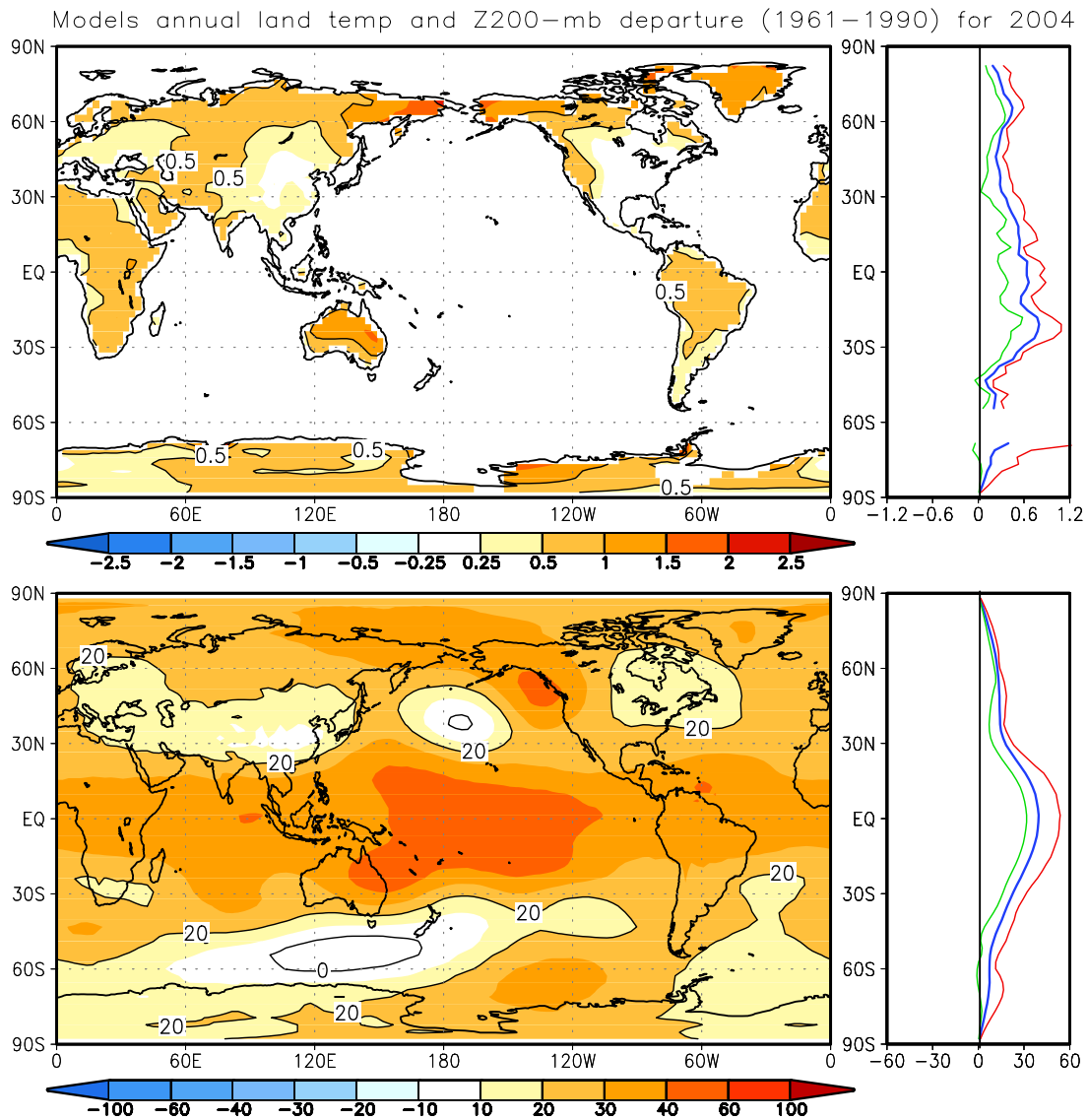


Fig. 3. The AGCM simulated 2004 annually averaged land surface temperature anomalies ( $^{\circ}\text{C}$ , top) and 200 mb geopotential height anomalies (m, bottom). Right side curves in top and bottom are the zonally averaged land surface temperature and 200 mb height anomalies, respectively. Extreme low (high) zonal mean values among the 5 AGCM ensembles denoted by green (red) curves. The AGCMs have been forced with the observed 2004 sea surface temperature anomalies, and the ensemble average of 81 simulations, from 5 AGCMs are shown. Reference period is 1961-1990 AGCM climatology.



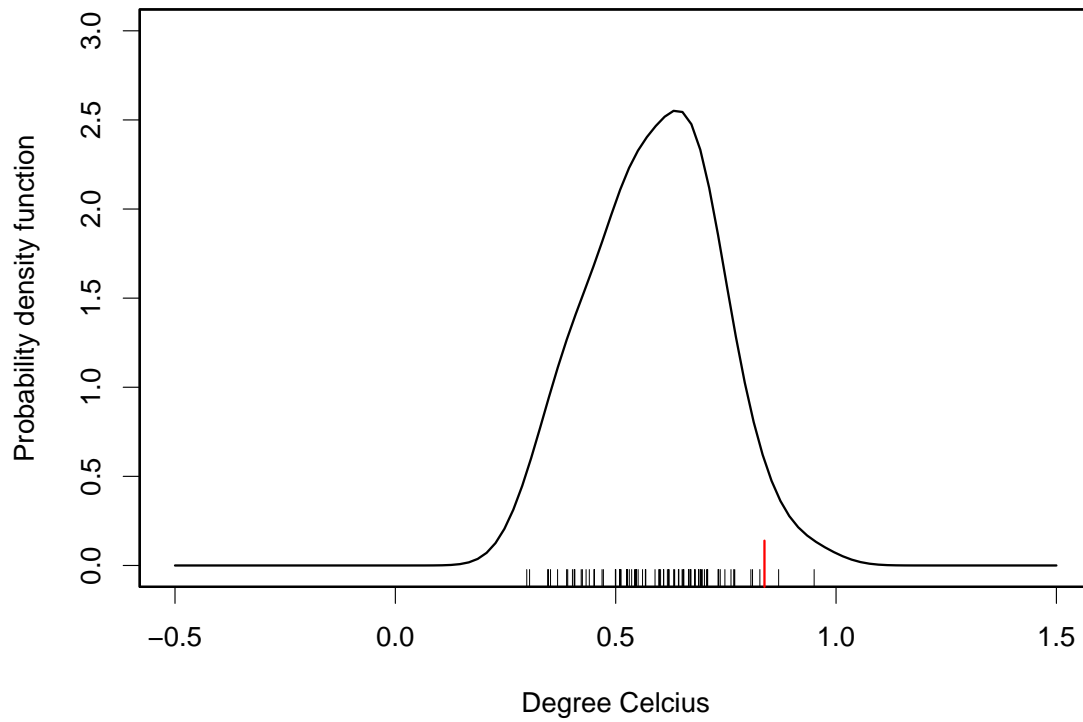


Fig. 4. Empirical probability distribution function (PDF) of the AGCM simulated 2004 annually averaged, globally averaged land surface temperature anomalies ( $^{\circ}\text{C}$ ). The data given by the solid line are from 81 individual AGCM responses to the 2004 sea surface temperature anomalies. The observed 2004 annually averaged, globally averaged land surface temperature anomaly shown by the long red tic mark. Reference period is 1961-1990.